LS-220

Survey and Alignment Report on The Primary Control Network for the APS

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Introduction

During November 1992 the survey and alignment team measured the entire primary control network for the APS. This task had to be finished before the enclosure of the EAA and the RF buildings were put in place, inhibiting several lines of sight necessary for the determination of the monument locations.

1. Purpose of the primary control network

The purpose of the primary control network is to ensure the correct location and orientation of each accelerator subsystem (see Fig. 3). In addition, some of the primary control points serve as connections to the tunnel control network.

The tunnel control network is a long and very narrow traverse. Computer simulations with this type of traverse have shown that the misclosure for the storage ring traverse, with a length of about 1104m, is in the range of ± 2cm assuming that no tie points to a primary control network are provided and distances are measured to ±0.3mm and directions to ±0.3mgon [1](Fig. 1).

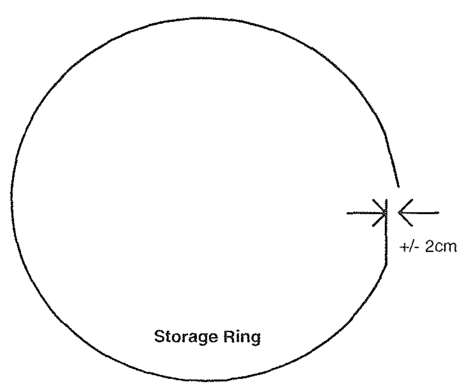

Fig. 1 Traverse misclosure

[1] 400 gon is equivalent to 360°. One mgon is 1/1000 of a one gon.

Another computer simulation using four connection points between the primary control network and the storage ring control network shows that the absolute positioning error is reduced to ±2mm half way in between two connection points. This estimated value is well within the given absolute positioning tolerance of ±5mm (Fig. 2). For this simulation the following measurement accuracy for the used instruments were used :

Mekometer distances :	±0.3mm
Wild T3000 directions :	±0.3mgon
Automatic nadir plumet Wild NL :	±0.5mm

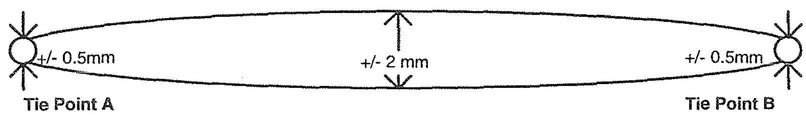

Fig. 2 Envelope of the absolute position error between two tie points

The primary control network for the APS was designed according to the results of these simulations.

2. Network design and coordinate system definition

The primary control network contains two connecting points to the linac control network, four equally spaced connections to the booster synchrotron control network, and four equally spaced connections to the storage ring control network (see Fig. 3). The coordinate system is defined as follows:

- The origin of the local geodetic coordinate system is at the center of the storage ring represented by monument MON00.
- The positive Z-axis is defined parallel to the direction of the linac.
- The X-axis is perpendicular to Z forming a right-handed coordinate system.
- The Y-axis is parallel to the gravity vector at MON00.

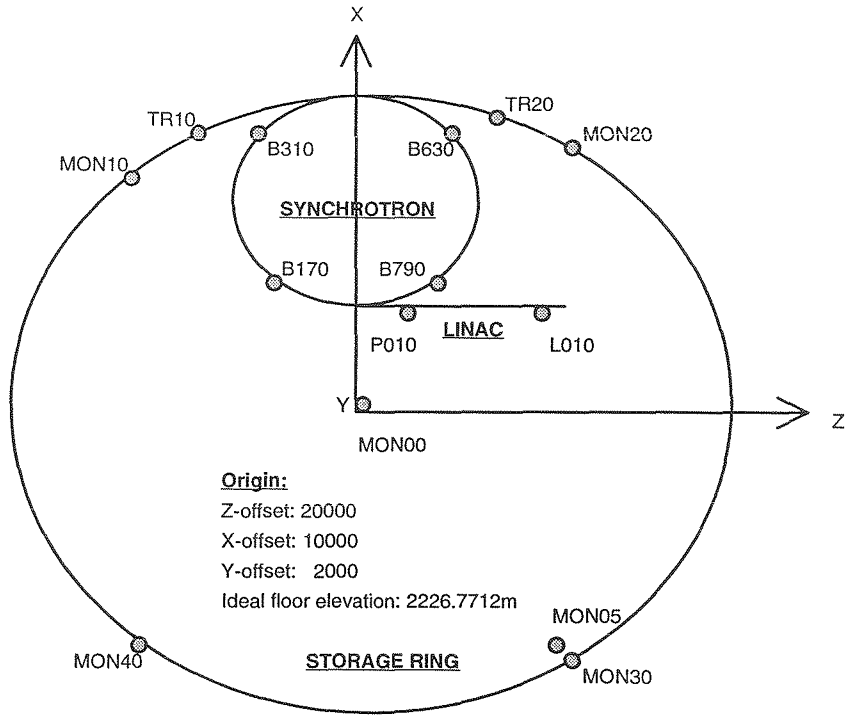

Fig. 3 APS primary control network

The geometric reference surface used for the APS is a locally best-fitting Gaussian sphere of Clark's reference ellipsoid at 41.704 degrees latitude, the approximate geographic location of the APS site (Fig. 4). The main parameters for Clark's ellipsoid [1] are :

Semi major axis	a :	6378206.4m
Eccentricity	e^2:	0.00676866
Radius of Gaussian sphere	R :	6348762.153m

The Gaussian sphere provides a third-order approximation of the gravity field in the vicinity of the origin. The differences between an ellipsoid, which is a second-order approximation of the gravity field, and a Gaussian sphere as reference surfaces are negligible for construction projects which span less than 1000 m from the origin [2].

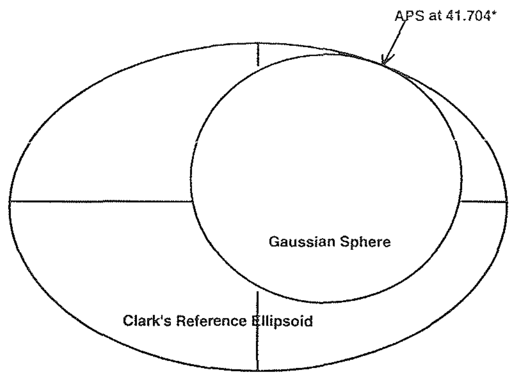

Fig. 4 Reference systems

The right-handed Cartesian coordinate system used for the lattice calculations has the same origin and orientation as the geodetic coordinate system where the (Z,X) plane is tangential to the Gaussian sphere at the center monument MON00.

The major difference between these two coordinate systems exists in the determination of the elevation. In the Cartesian coordinate system the Y coordinate refers to the (Z,X) plane and is independent of the location in that plane, while in the local geodetic coordinate system the elevation Y refers to the Gaussian sphere and changes with increasing distance from the origin. For the APS storage ring the difference between rectangular and geodetic elevations is 2.4mm and has to be taken into account for the placement of the beam components [3] (see Fig. 5).

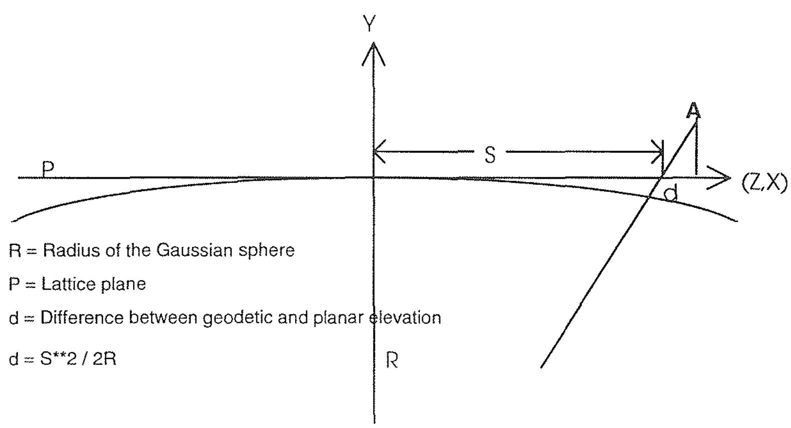

Fig. 5 Elevation difference between
rectangular and geodetic coordinates

The ideal floor elevation for the APS was defined at 226.7712m above mean sea level. The beam height was defined at 1.40m above the ideal floor elevation. Settlement surveys through the linac, booster synchrotron, and storage ring showed deviations of up to ± 2.5cm from the ideal floor height. The largest deviations were found in the synchrotron ring and the linac. The support stands for the beam components of these areas have to be built to accommodate these deviations.

3. Survey Measurements

Before any measurements were taken, an error analysis of the primary control network using different observation plans was performed. As a result of this study it was decided to use trilateration only, to measure the primary control network. The measurement technique of modern electronic distance measurement devices has advanced to the point that a trilateration network can be determined with better accuracy than a triangulation network. It can also be shown that a combination of angular and distance measurements does not improve the accuracy of the network. For the error analysis it was assumed that the distances of the APS primary control network can be measured to ±0.2mm. The expected maximum position accuracy of the monuments is then ±0.3mm.

For the distance measurements of the APS primary control network a ME5000 from Kern was used. This instrument measures distances from 10m to 8000m to an accuracy of

$$a = 0.2\text{mm} + 0.2\text{mm/Km}$$

In order to obtain that accuracy, the meteorological conditions (temperature, relative humidity, pressure) at each station and target have to be recorded before and after each distance measurement. For the geometric reduction to the reference surface the elevation of each station and target has to be known. The elevation measurements were done with a Wild N3 spirit level.

4. Survey Results

The observation plan required the distance measurement of each visible target from each primary network control point. This gives sufficient redundancy to obtain statistical confidence of the location of all control points after the data has been processed using least squares adjustment programs. The orientation of the network is given by MON00 and the direction to MON05. Table 1 lists the adjusted coordinates and the parameters of the absolute error ellipses for each primary control network point of the first measurement epoch.

Table 1

Adjusted Coordinates and Standard Error Ellipse Parameters from Nov. 1992

Point	*Z* [m]	*X* [m]	*Phi* [gon]	*A* [m]	*B* [m]
MON00	20000.00000	10000.00000	56.1	0.00020	0.00016
MON05	20096.74258	9866.84526	65.3	0.00021	0.00015
MON10	19897.53167	10141.01224	37.7	0.00025	0.00011
MON20	20141.02639	10102.46023	176.8	0.00020	0.00015
MON30	20102.46269	9858.96277	51.4	0.00025	0.00015
MON40	19858.98390	9897.52269	188.6	0.00020	0.00014
TR10	19920.84397	10155.33077	51.1	0.00025	0.00015
TR20	20102.45421	10141.02704	104.2	0.00026	0.00018
B790	20044.50760	10077.29533	7.1	0.00023	0.00012
B630	20057.15758	10144.83342	52.8	0.00023	0.00017
B310	19938.68499	10136.40232	26.8	0.00024	0.00013
B170	19955.48515	10077.29714	35.1	0.00016	0.00012
P010	20035.27221	10067.64959	3.5	0.00023	0.00013
L010	20120.38374	10066.31174	35.6	0.00013	0.00010

The standard error ellipses represent the area of uncertainty for each control point location. The parameters of these error ellipses are *A* the semi major axis, *B* the semi minor axis, and *Phi* the azimuth of the major axis of the ellipse in gon [4]. A graphical representation of the primary control network of the APS and the associated error ellipses is given in Fig. 6.

The values for the semi major and semi minor axes coincide very well with the values derived through the error analysis. To obtain the 3σ confidence ellipse [5] both axes have to be scaled by a factor of about 2.5. The degree of freedom for this adjustment is 80 and the mean square error for the distances is 0.67 mm.

5. References

[1] W. Grossmann, Geodätische Rechnungen und Abbildungen in der Landesvermessung, Verlag Konrad Wittwer, Stuttgart, 1964.

[2] SLC Design Handbook, SLAC Stanford University, 1984.

[3] W. Torge, Geodesy, Sammlung Göschen, Verlag de Gruyter, 1975.

[4] I. Burstedde, *"Adjustments of Geodetic Networks at SLAC," 1983.*

[5] W. Grossmann, Grundzüge der Ausgleichungsrechnung, Springer Verlag, 1968.

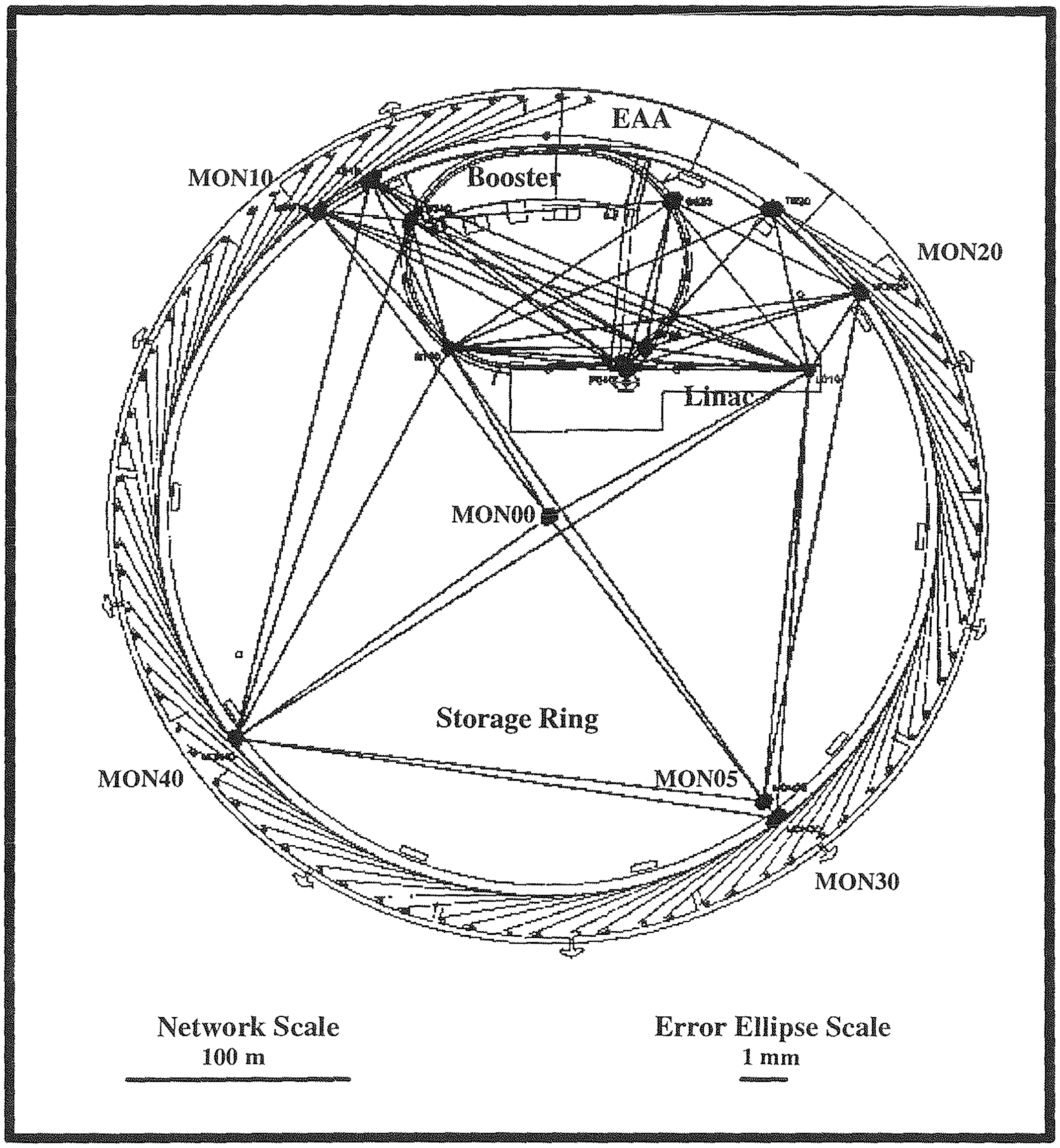

Fig.6 APS primary control network